
LITERATURE REVIEW

Learning spinal manipulation: *A best-evidence synthesis of teaching methods**

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Objective: The purpose of this study was to evaluate the effectiveness of different reported methods used to teach spinal manipulative therapy to chiropractic students.

Methods: For this best-evidence literature synthesis, 5 electronic databases were searched from 1900 to 2015. Eligible studies were critically appraised using the criteria of the Scottish Intercollegiate Guidelines Network. Scientifically admissible studies were synthesized following best-evidence synthesis principles.

Results: Twenty articles were critically appraised, including 9 randomized clinical trials, 9 cohort studies, and 2 systematic reviews/meta-analyses. Eleven articles were accepted as scientifically admissible. The type of teaching method aids included a Thrust in Motion cervical manikin, instrumented cardiopulmonary reanimation manikin, padded contact with a load cell, instrumented treatment table with force sensor/transducer, and Dynadjust instrument.

Conclusions: Several different methods exist in the literature for teaching spinal manipulative therapy techniques; however, future research in this developing area of chiropractic education is proposed. It is suggested that various teaching methods be included in the regular curricula of chiropractic colleges to aid in developing manipulation skills, efficiency, and knowledge of performance.

Key Indexing Terms: Manipulation; Spinal; Education; Chiropractic; Learning

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INTRODUCTION

Spinal manipulative therapy (SMT) is the treatment procedure used most frequently by doctors of chiropractic.¹ It has been characterized by applying a dynamic high-velocity low-amplitude thrust into a specific contact on the patient's body.² Chiropractic students learn how to perform this skill during their training years at a chiropractic institution.¹ The format and amount of time spent training to learn spinal manipulation skills can range from formalized curricula in professional programs to weekend seminars and individual demonstrations; however, each chiropractic college teaches core manipulation procedures.³ In comparison to other professional programs that teach spinal manipulation, such as the doctor of osteopathy, doctor of medicine, and master of physiotherapy programs, doctor of chiropractic programs in both Canada and the United States offers

extensive hours of training specifically in the skill of spinal manipulation in order to train chiropractors to be proficient.³ Teaching high-velocity, low-amplitude (HVLA) spinal manipulation within the chiropractic educational curriculum involves issues in relation to tradition, safety, and effectiveness in the application of this treatment procedure.⁴ For students to perform manual SMT properly, they must first learn how to control the amount of force applied and master overall body coordination.¹ In most chiropractic schools, the type of teaching method most utilized for accomplishment of these skills is known as knowledge of performance.⁵

Historically, the usual teaching procedure begins with students learning the theoretical aspects of HVLA SMT, followed by a demonstration by an instructor performing a specific spinal manipulation and students imitating the instructed procedure on their fellow classmates.⁴ As students carry out the task, they attempt to mimic the clinician's positions, hand placement, direction of force, and the amount and control of that specific force delivered during performance of the technique method.⁴ Students may grasp the knowledge of performance skills partially or completely during the various years and levels of their training.⁴

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Practicing on classmates allows students to simulate a real doctor–patient interaction.¹ Unfortunately, as students are initially novices performing SMT, it is possible that injuries may occur.⁶ A survey conducted by Ndetan and his colleagues revealed that chiropractic students sustained injuries at all levels of training.⁶ They reported that the most prevalent injuries from receiving manipulations were neck and shoulder pain, while hand and wrist injuries were most prevalent for administering manipulations.⁶ It would be in the best interest of chiropractic institutions to use or design new teaching methods and protocols that may prevent injury to students during their training program and optimize safety in the learning of SMT techniques.⁶

Mechanical training aids are becoming more common as an additional method for teaching SMT to students.⁷ Some examples of mechanical training aids include ground force plates to measure weight transfer, instrumented manikins, visual feedback of force–time profiles, and force-sensing chiropractic tables. These mechanical training aids allow for more quantitative feedback while performing SMT, in contrast to the currently utilized method of learning how to perform in which students most often receive only verbal feedback.⁷ Some studies have reported that both knowledge of performance and mechanical training aids have been shown to facilitate learning and can transfer to real-life clinical situations.⁷ Between these 2 methods, it appears that chiropractic students may sustain fewer injuries when they learn how to perform SMT using mechanical training aids.⁷ Many of these mechanical training aids are emerging and being utilized in chiropractic schools at different stages of the curriculum in doctor of chiropractic programs. Several articles have shown the effectiveness of these teaching methods in the learning experience of chiropractic students.^{1,3–6,8–20}

The purpose of our literature synthesis review was to evaluate the effectiveness of various teaching methods used to teach SMT procedures in chiropractic students as a population.

METHODS

Eligibility Criteria

Population

Our review targeted studies that taught manual SMT procedures to chiropractic students. Studies were excluded if they did not include chiropractic students, utilized instrument-assisted forms of SMT (eg, the Activator instrument, Integrator-Torque Release instrument, or ProAdjuster), or did not specifically include spinal manipulation as the required learning task. Spinal manipulation was defined according to the definition proposed by Descarreaux and colleague:¹⁵

“Chiropractic spinal manipulation is commonly described as a specific form of articular manipulation with either long or short leverage techniques and specific anatomical contacts.

Characterized by a dynamic thrust of high velocity, low amplitude, specific contact and direction associated with an audible cavitation, it can be seen as an action requiring high-

speed, low-amplitude precision that has mechanical consequences.”

Interventions

In order to examine the effectiveness of methods used to teach SMT to chiropractic students, studies that used methods other than instructor simulation and/or verbal feedback were considered in the intervention group. Teaching methods could include visual or biofeedback, instrumented manikins, instrumented training devices, ground force plates, and/or force-sensing treatment tables. Studies that examined only the biomechanical parameters involved in spinal manipulation that did not directly apply to teaching methods were not included.

Comparison Groups

Studies that compared novel teaching method aids to standard training methods followed by various chiropractic curriculums were included. In addition, studies that compared the participants’ different levels of study, years of SMT technique experience, and type of training mode were included.

Outcomes

To be eligible, studies had to include either a quantitative or qualitative evaluation of the performance of a spinal manipulation. A quantitative evaluation consisted of a comparison of biomechanical HVLA spinal manipulation obtained from a load-time history graph. A qualitative evaluation included verbal feedback by an evaluator or simulated patient as to whether the participant’s performance was analogous to an ideal spinal manipulation.

Study Characteristics

Eligible studies met the following criteria: (1) English language; (2) published between January 1, 1900 to June 2015; (3) evidence-based guidelines, systematic reviews, meta-analyses, randomized clinical trials (blinded and nonblinded), nonrandomized trials, cohort studies (prospective and historical), case-control studies, and cross-sectional studies; (4) articles in which a manipulative skill was taught to chiropractic students with performance outcome measures that could have been quantitative or qualitative in nature. Studies with the following characteristics were excluded: (1) poster presentations, letters, editorials, commentaries, unpublished manuscripts, government reports, book and book chapters, conference proceedings, meeting abstracts, lectures and addresses, consensus development statements or guideline statements; (2) cadaveric or animal studies; (3) instrument-assisted spinal manipulation techniques. (See Tables 1–3.)

Information Sources

A search strategy was developed with a health sciences reference librarian to identify relevant titles and abstracts published from 1900 to June 2015. The PubMed, Index to

Table 1 - Risk of Bias for Accepted RCTs Based on the Scottish Intercollegiate Guidelines Network (SIGN) Criteria

Author, Year, Evidence Level, Reference	Research Question	Randomization	Concealment	Blinding	Similarity at Baseline	Difference Between Groups	Outcome Measurement	Percent Drop-out ^a	Intention to Treat	Multiple Sites
Young T, Hayek R, Philipson S, 1998 (+) ⁸	AA	AA	PA	AA	WC	WC	PA	No mention (assume 0%)	NAp	NAp
Triano JJ, Rogers CM, Combs S, Potts D, Sorrels K, 2002 (+) ⁹	AA	PA	NR	NR	WC	WC	WC	5.13%	NAp	NAp
Scaringe JG, Chen D, Ross D, 2002 (+) ¹⁰	AA	PA	AA	NR	WC	WC	AA	12.6%	NAp	NAp
Triano JJ, Scaringe J, Bougie J, Rogers C, 2006 (+) ¹¹	AA	PA	AA	PA	WC	WC	WC	No mention (assume 0%)	NAp	NAp
Enebo B, Sherwood D, 2005 (+) ⁵	AA	PA	NR	NR	AA	AA	AA	No mention (assume 0%)	NAp	NAp
Descarreaux M, Dugas C, Lallane K, Vincelette M, Normand MC, 2006 (+) ¹	AA	PA	NR	NR	AA	AA	AA	No mention (assume 0%)	NAp	NAp
Triano JJ, Rogers C, Combs S, Potts D, Sorrels K, 2003 (+) ¹³	AA	PA	NR	NR	WC	WC	WC	5.13%	NAp	NAp

^a Percent drop-out incorporates both participant withdrawal and loss to follow-up.

WC indicates well covered; AA, adequately addressed; PA, poorly addressed; NR, not reported; NAp, not applicable.

Table 2 - Risk of Bias for Accepted Cohort Studies Based on the Scottish Intercollegiate Guidelines Network (SIGN) Criteria

Author, Year, Evidence Level, Reference	Research Question	Cohorts From Comparable Source Populations	Indicated Number of Volunteers/Participants	Percent Drop-out ^a	Comparison Between Cohorts, Assessed More than 1		Method of Assessment, Reliability, Evidence From Other Sources		Main Potential Confounders	Confidence Interval
					Outcome Measurement	Blinding	Outcome Measurement	Blinding		
Descarreaux M, Dugas C, Raymond J, Normand MC, 2005 (+) ¹	AA	WC	WC	No mention (assume 0%)	NAp	NR	AA	AA	NAp	AA
Harvey MP, Wynd S, Richardson L, Dugas C, Descarreaux M, 2011 (+) ⁴	AA	AA	AA	1.14%	NAd	NR	AA	AA	NAd	AA
Triano JJ, Gissler T, Forgie M, Milwid D, 2011 (+) ¹²	AA	AA	WC	No mention (assume 0%)	NAp	NR	AA	AA	PA	WC
Triano JJ, Bougie J, Rogers C, et al., 2004 (+) ³	AA	WC	WC	No mention (assume 0%)	NAp	NR	AA	AA	NAd	AA

^a Percent drop-out incorporates both participant withdrawal and loss to follow-up.

WC indicates well covered; AA, adequately addressed; PA, poorly addressed; NR, not reported; NAp, not applicable; NAd, not addressed.

Table 3 - Characteristics of Included Studies

Study	Study Design	Target Population	Study Population	Outcome	Follow-up Period	Key Results
Young T, Hayek R, Philipson S, 1998 ⁸	Randomized control trial	Chiropractic students	4th-year master's of chiropractic students at Macquerie University, no prior spinal adjusting experience ($n = 20$)	Grading ranged from 0 to 3 of technical parts of cervical spinal manipulation.	Not applicable	Intervention group average marks = 2.17; control group average marks = 2.13; no significant difference ($p = .985$).
Triano JJ, Rogers CM, Combs S, Potts D, Sorrels K, 2002 ⁹	Randomized control trial	Chiropractic students	Students entering training at the Texas Chiropractic College ($n = 39$)	Load-time history measure characteristics of diversified, mammillary-push procedure in the lumbar spine	Over a 1-trimester term	Significant changes in performance between the standard curriculum and modified curriculum were observed in several biomechanical parameters (preload values [$p = .0009$], mean rate of force increased [$p = .0000$]).
Scaringe JG, Chen D, Ross D, 2002 ¹⁰	Randomized control trial	Chiropractic students	Chiropractic students, no experience with experimental apparatus nor knowledge of the hypotheses being tested ($n = 71$)	Absolute constant error measure of performance accuracy; variable error determines performance consistency	1-day group; 5-day group; 8-day group	No significant main effect for the 2 feedback groups was found for constant error and variable error during the acquisition and retention phase; subjects were less accurate as time between acquisition and retention trial increased ($p < .05$).

Table 3 – Continued.

Study	Study Design	Target Population	Study Population	Outcome	Follow-up Period	Key Results
Triano JJ, Scaringe J, Bougie J, Rogers C, 2006 ¹¹	Randomized control trial	Chiropractic students	Chiropractic students from the 2nd year, in their first term, absence of any formal training in the test task, willingness to participate ($n = 40$)	Load-time history measures characteristics of diversified, mammillary-push procedure in the lumbar spine; 5-item visual analog evaluation instrument with 6 parameters.	Not applicable	The group that received immediate visual feedback of their load time histories resulted in immediate and significant improvement in all measured parameters (speed [$p < .006$], moment [$p < .008$], and mean force production [$p < .008$]).
Enebo B, Sherwood D, 2005 ⁵	Randomized control trial	Chiropractic students	Chiropractic students enrolled in the first 4 semesters ($n = 33$)	Constant error (accuracy), absolute constant error (accuracy without regard of direction), and variable error (consistency)	Not applicable	There was no significant main effect of feedback for constant error and variable error in force production ($p = .05$).
Descarreaux M, Dugas C, Raymond J, Normand MC, 2005 ¹	Cohort study	Chiropractic students	For students: enrolled in chiropractic program (2nd year, 4th year, and interns). For chiropractors: ≥ 5 years of clinic practice, licensed to practice in Quebec ($n = 43$)	Load-time history measure characteristics of thoracic spinal manipulation	Not applicable	No group difference was observed for the peak force, peak force variability, and preload force variables. Participants without clinical experience showed longer time-to-peak force values ($p = .012$), increased time-to-peak force variability ($p = .007$), and a smaller mean rate of force production ($p = .032$).

Table 3 – Continued.

Study	Study Design	Target Population	Study Population	Outcome	Follow-up Period	Key Results
Descarreaux M, Dugas C, Lalanne K, Vincelette M, Normand MC, 2006 ⁷	Randomized control trial	Chiropractic students	4th-year students enrolled in chiropractic program, (n = 31)	Load-time history measure characteristics of thoracic spinal manipulation	Not applicable	Both groups showed decrease in peak force applied. Participants in the feedback training group significantly reduced their peak force variability ($p = .024$) and significantly increased their preload force ($p < .001$).
Harvey MP, Wynd S, Richardson L, Dugas C, Descarreaux M, 2011 ⁴	Cohort study	Chiropractic students	Students enrolled in chiropractic college; entering or first few weeks before internship, had accumulated similar amounts of formal laboratory training in technique classes (n = 88)	Load-time history measure characteristics of prone unilateral hypothenar transverse push thoracic spine manipulations	Not applicable	Group 2 (complete practice of spinal manipulation skills) demonstrated more favorable spinal manipulation parameters (lower time-to-peak force values [$p = .02$], higher peak force [$p < .0001$], and steeper rate of force production [$p < .004$] compared to group 1 (patient–doctor positioning practice model).
Triano JJ, Gissler T, Forgie M, Milwid D, 2011 ¹²	Cohort	Chiropractic students	Students enrolled in chiropractic college, graduate clinicians, faculty of the teaching clinic, and to those with ≥ 5 years of active practice experience using high-velocity, low-amplitude (HVLA) procedures (n = 50)	Load-time history measure characteristics of prone unilateral hypothenar transverse push thoracic spine manipulations	Not applicable	Evidence suggested that the majority of development occurs in year 3 of study ($p < .001$).

Table 3 – Continued.

Study	Study Design	Target Population	Study Population	Outcome	Follow-up Period	Key Results
Triano JJ, Bougie J, Rogers C, et al. 2004 ³	Cohort study	Chiropractic students	Chiropractic students with the absence of formal training in the L4 mammillary process manipulation and willingness to participate both as simulated patient receiving spinal manipulation and as a simulated doctor administering the spinal manipulation ($n = 77$)	Load-time history measure characteristics of diversified, mammillary-push procedure in the lumbar spine	Not applicable	Program 2, which has more credit hours of laboratory work, was more similar to the expert reference standard than program 1, which has more credit hours of didactic presentation lectures ($p = .0000$).
Triano JJ, Rogers C, Combs S, Potts D, Sorrels K, 2003 ¹³	Randomized control trial	Chiropractic students	Students entering training at the Texas Chiropractic College ($n = 39$)	Load-time history measure characteristics of thoracic and cervical spinal manipulation	Over a 1-trimester term	Significant changes in performance between the standard curriculum and modified curriculum (with the Dynadjust) were observed for several, but different, biomechanical parameters of cervical and thoracic procedures (axial force [$p = .0365$], sagittal force [$p = .0458$], and sagittal moment [$p = .0395$]).

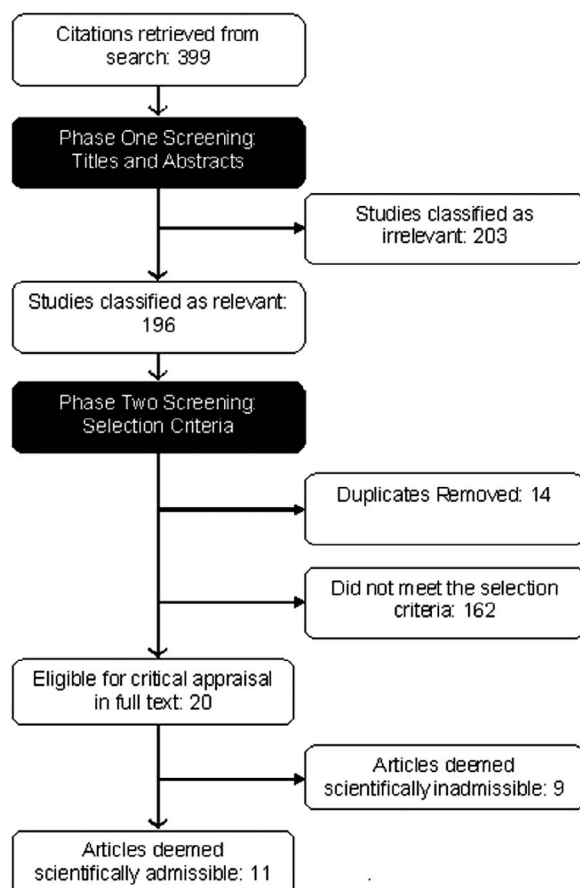


Figure 1 - Flow diagram showing inclusion and exclusion of the papers in this review.

Chiropractic Literature, ALT Health Watch, MEDLINE, and CINAHL databases were searched. The search strategy was first developed in MEDLINE and subsequently adapted to the other bibliographic databases. The search terms included subject headings (eg, MeSH) specific to each database and included “spinal manipulation,” “education,” and “chiropractic.” A bibliographic database was used to manage the search results, and all results were organized into Excel for screening.

Study Selection

The titles and abstracts of retrieved studies were screened to determine eligibility for inclusion into the literature review. A 2-phase screening process was used to select eligible studies. In the first phase, 2 independent reviewers screened citation titles and abstracts to determine eligibility of studies. Phase 1 screening resulted in studies being classified as relevant, possibly relevant, or irrelevant. In phase 2, the same pair of reviewers independently screened the possibly relevant studies to determine eligibility. The reviewers met to resolve disagreements and reach consensus on the eligibility of studies. A third reviewer was available but not utilized as consensus was reached between both independent reviewers to determine study eligibility (Fig. 1). Full-text versions of all studies determined to

be eligible were obtained, and a hand search of the reference lists of the relevant articles was conducted to identify additional studies.

Assessment of Risk of Bias

Two independent reviewers critically appraised the internal validity of eligible studies using the Scottish Intercollegiate Guidelines Network (SIGN) criteria.²¹ The SIGN criteria were used to qualitatively evaluate the presence and impact of selection bias, information bias, and confounding on the results of a study.²¹ A quantitative score or cutpoint to determine the internal validity of studies was not used; rather, the SIGN criteria were used to assist reviewers to make an overall informed judgment on the internal validity of studies.²¹ Specifically, critical appraisal is focused on the following methodological aspects of a study: (1) clarity of the research question, (2) randomization method, (3) concealment of treatment allocation, (4) blinding of treatment and outcomes, (5) similarity of baseline characteristics between/among treatment arms, (6) cointervention contamination, (7) validity and reliability of outcome measures, (8) follow-up rates, (9) analysis according to intention to treat principles, and (10) comparability of results across study sites (where applicable).²¹ Reviewers reached consensus through discussion. An independent third reviewer was to be used to resolve disagreements if consensus could not be reached; however, that reviewer was not required. Studies found to have adequate internal validity and low risk of bias were included in this best-evidence literature synthesis.

Data Extraction and Synthesis of Results

One of the reviewers extracted data from the included studies to build evidence tables. The second reviewer independently checked the extracted data. The authors performed a best-evidence synthesis approach using only internally valid studies in order to minimize bias. According to Slavin,²² “best-evidence syntheses focus on the ‘best evidence’ in a field, the studies highest in internal and external validity, using well-specified and defended a priori inclusion criteria, and use effect size data as an adjunct to a full discussion of the literature being reviewed.”²²

RESULTS

Study Selection

We retrieved 399 articles with our search. The phase 1 screening process (review of titles and abstracts) classified 203 studies as being irrelevant and 196 studies as being possibly relevant or relevant. The phase 2 screening removed 14 duplicates and found 162 articles that did not meet selection criteria. As a result, 20 articles were critically appraised. Eleven articles were found to be scientifically admissible (Fig. 1).

Study Characteristics

Among the 11 scientifically admissible studies, 4 were cohort studies and 7 were randomized clinical trials. Of

those, 1 article evaluated cervical spinal manipulation,⁸ 6 articles evaluated thoracic spinal manipulation,^{1,4,5,7,10,12} and 3 articles evaluated lumbar spinal manipulation.^{3,9,11} One randomized clinical trial (RCT) evaluated both cervical and thoracic spinal manipulation.¹³

The teaching aids used in the studies were varied. The authors identified 5 different types of teaching aids: noninstrumented Thrust in Motion cervical (TMC) manikin (Macquarie University Centre for Chiropractic, Sydney, Australia),⁷ instrumented cardiopulmonary reanimation (CPR) manikin,^{7,8,10} instrumented treatment table embedded with force sensor/transducer,^{3,9-13} and Dynadjust instrument (Ortho Neuro Technologies, Seattle, WA),^{9,13} and a load cell attached to a padded contact.⁵

Risk of Bias Assessment Within Studies

Of the 20 critically appraised studies, 9 studies (45%) were rejected. The weaknesses of the excluded studies included failure to describe adequate methods for retrieving selected articles in a systematic review,¹⁴ studies not relevant to key question,^{2,3,16,17} a longitudinal observational study,¹⁵ poster presentations,^{18,19} and study population not directed toward chiropractic students.²⁰

The 11 included studies were deemed to be of acceptable quality using the RCT and cohort studies SIGN checklists.²¹ No articles were found to be of high quality. All 7 RCTs (Table 1) were able to adequately address the research question, were single-site studies, and accounted for all participants. The baseline characteristics and differences between groups were appropriately addressed and very similar for all studies.^{5,7-11,13} Most studies mentioned randomization; however, allocation of participants was poorly addressed.^{5,7,9-11,13} Four studies did not report whether concealment or blinding was used.^{5,7,9,13} Due to the nature of the study, concealment and blinding may not have been appropriate or possible, and this was considered during critical appraisal.

All 4 cohort studies (Table 2) adequately addressed the research question, had cohorts comparable to the source population, indicated the number of participants involved, and clearly defined the outcome measurement.^{1,3,4,12} Similar to the RCT studies, blinding was not reported for all 4 cohort studies, and it was noted that blinding was likely not appropriate or possible.^{1,3,4,12} In addition, all cohort studies used appropriate methods of assessment for reliability and evidence from other sources.^{1,3,4,12}

Summary of Evidence

Table 3 provides a summary of the studies included in this review, including the study designs, sample, and key results. Information pertaining to specific device types is presented in detail below.

Thrust in Motion Cervical Manikin

One RCT used a TMC as a teaching aid for chiropractic students to practice HVLA cervical manipulation.⁸ The manikin is life-size with a flexible plastic neck that allowed students to develop the gross procedural and psychomotor skills involved in cervical spinal manipulation.⁸ This study used a qualitative outcome

measure of the technical parts of a cervical manipulation, such as line of drive, adequate velocity, short amplitude, and good control of head and neck.⁸ Blinded examiners evaluated students' performance of cervical spinal manipulations by giving them a mark.⁸ Evidence suggests that there are no significant differences between examination scores of the group that used only the TMC manikin to practice (mean: 2.17 points; $n = 6$; SD 0.72) and the group that had hands-on practice (mean: 2.13 points; $n = 14$; SD 0.69) with performing cervical manipulations to their fellow students (2-sample t test, $p = .985$).⁸

Instrumented Cardiopulmonary Reanimation Manikin

Two cohort studies^{1,4} and one RCT⁷ used an instrumented CPR manikin as a teaching aid for practicing and evaluating thoracic spinal manipulations by chiropractic students. The manikin, originally designed to teach CPR, was modified and instrumented with a spring to emulate resistance similar to that of the thoracic spine, and a strain gauge (Model UL 400, Statham, Oxnard, CA) was installed at the top of the spring.^{1,4,7} This was used to record the vertical forces being applied by the students.^{1,4,7} An electromagnet was then mounted at the base of the spring to limit the posterior-anterior movement of the manikin.^{1,4,7} This was controlled by the experimenter to be near the mean force normally applied in a thoracic spinal manipulation (450–475 N).^{1,4,7} Once a manipulation procedure was applied to the manikin, the signals were analyzed to determine load-time parameters of the SMT.^{1,4,7} Onset of force, peak force applied, and preload force data were obtained.^{1,4,7} From these data, time-to-peak force, time-to-peak force variability, peak force variability, and rate of force production were calculated.^{1,4,7} In all studies, the participants also stood on a ground force plate that measured the onset of unloading and unloading time.^{1,4,7} These load-time parameters were the quantitative outcome measurements used for all 3 studies.^{1,4,7}

One cohort study¹ measured the load-time parameters of a thoracic SMT in different groups of subjects with various levels of expertise at Université du Québec à Trois-Rivières. The groups consisted of 2nd-year chiropractic students, 4th-year chiropractic students, chiropractic interns, and licensed chiropractors.¹ The authors found that after completing 10 consecutive SMT procedures on the instrumented CPR manikin without feedback, the groups with no clinical experience (2nd- and 4th-year students) demonstrated significantly different load-time parameters: (longer time-to-peak force values) ($p = .012$), increased time-to-peak force variability ($p = .007$), and a smaller rate of force production ($p = .032$) compared to the chiropractic interns and licensed chiropractors ($p < .05$).¹ Another cohort study compared the teaching models used to teach HVLA thoracic SMT.⁴ One cohort focused more on teaching patient-doctor positioning of setting-up to perform a manipulation without a thrusting component, while the other cohort performed actual manipulations on their fellow students.⁴ Evidence showed that students in

the group where actual SMTs (thrusting was permitted) were performed had better load-time parameters: lower time-to-peak force values ($p = .02$), higher peak force ($p < .0001$), and a steeper rate of force production ($p < .004$).⁴

The 1 RCT⁷ used an instrumented CPR manikin and compared different methods of feedback. The control group followed standard training, which consisted of receiving feedback from experienced chiropractors and practicing the SMTs on their fellow classmates.⁷ The intervention group practiced SMTs on the manikins, and feedback was given by seeing the load-time history curve on a large screen placed in front of them.⁷ The intervention group showed a significant reduction in their peak force variability (mean 25.8 ± 4.5 N, $p = .024$) and increased their preload force (mean 110.6 ± 17.3 , $p < .001$).⁷

Padded Contact With a Load Cell

One RCT⁵ used a padded contact with a load cell attached to measure the force applied by the participants. The padded contact plate is 0.69 m from the ground and is attached to the load cell with a 0.55-m-long aluminum arm.⁵ A universal serial bus (USB) data acquisition system read the load cell output, and the data were passed to a computer for visual feedback and data recording.⁵ The load cell (Omega Engineering Inc, Stamford, CT) had 2 compression springs (Century Spring Corp, Los Angeles, CA) in parallel to provide resistance in the downward movement to emulate the thoracic spine from cadaveric studies.⁵ The load cell only measures in the downward plane; movements in other planes were minimized.⁵ The testing device was constructed to simulate a posterior-anterior SMT procedure with vertical displacement (patient in a prone position).⁵ In the study, participants were randomly assigned to 2 groups and were asked to perform SMT procedures with 3 predetermined force goals (35%, 55%, and 80% of maximum force-producing ability, with a preload force value of 10% of maximum force-producing ability) onto the testing apparatus.⁵ Acquisition and retention trials were performed for each force percentage in both blocked and random variable practice.⁵ The intervention group was allowed real-time viewing of their force load outputs in a computer (visual feedback) and improved their force production accuracy in the retention phase ($p = .04$) compared to the control group that received only verbal feedback from an examiner.⁵

Instrumented Treatment Table With Force Sensor/Transducer

Four studies^{3,10-12} used an instrumented treatment table. One RCT¹⁰ used a force transducer (Impulse Sports Training Systems, Bay Village, OH) consisting of a piezoelectric film adhered to a sheet of plastic that is embedded in a 1-inch-thick foam rubber padded bag. The device was then secured to a variable-height treatment table.¹⁰ Voltage readouts of the participant's force were displayed in a computer.¹⁰ Participants were randomly assigned into 2 groups (intervention vs control) and were asked to perform a thoracic SMT procedure.¹⁰ Evidence showed that there was no significant main effect between

the groups receiving feedback with digital displays of their force output vs the group that received only verbal feedback from the examiner ($p > .05$).¹⁰

For the other 3 studies, 1 RCT¹¹ and 2 cohort studies,^{3,12} the same type of instrumented treatment table was used. A commercial treatment table (Leader 900 Z Series, Leader International Corp, Port Orchard, WA) was modified.^{3,11,12} An Advanced Medical Technology, Inc (Watertown, MA) force plate was imbedded in the treatment table that can sense forces and moments about 3 planes through arrays of strain gauges located at its 4 corners.^{3,11,12} In addition, there were special feature modifications included, such as an artificial shoulder to stabilize the operator's body mass, a lateral barrier to stabilize the patient's upper body mass, and a webbed strap to constrain upper body motion.^{3,11,12} The forces and moments data from the force plate were passed through a computer, where a load-time history curve was created and displayed on a computer screen.^{3,11,12}

The student participants in the RCT¹¹ study were paired and then randomly assigned to 2 groups (intervention vs control). The test task was to perform a lumbar SMT procedure on their partners on the instrumented treatment table.¹¹ The group that received immediate visual feedback of their load-time histories had immediate and significant improvement in all measured parameters (speeds increased for force [$2132-2761$ N/s, $p < .006$], moment [$477-781$ Nm/s, $p < .008$], and mean force production [$312-372$ N, $p < .008$]) compared to the control group that received no feedback at all.¹¹

The cohort study by Triano et al.¹² compared the biomechanical parameters of a HVLA SMT of participants in different level of experience. The cohorts consisted of students in years 1-4, and chiropractors in practice (experience of 5 years or greater).¹² All cohorts were paired with another participant closest in height (within a range of ± 8 cm) to minimize variation, and each performed a thoracic SMT on a subject lying prone on an instrumented treatment table.¹² The authors found a natural maturation in HVLA force development during training.¹² Evidence suggested that the majority of development occurs in year 3 of study (peak force 397 ± 96 N, force rate 3183 ± 1023 N/s, and rise time 0.152 ± 0.035 seconds), with tapering through year 4 ($p < .001$).¹²

The other cohort study, using the same instrumented treatment table, compared the prerequisite requirements to manipulation training.³ The test task used was a lumbar SMT procedure performed on the paired participants.³ They found significant differences in the biomechanical parameters of the SMT between cohorts as they compared them to experts, who were practicing chiropractors with clinical experience ranging from 8 to 30 years.³ They found that the SMT parameters of the program with more credit hours of laboratory hands-on work (force 321.4 ± 112.6 N and moment 86.2 ± 36.6 Nm, $p < .001$) were more similar to the experts (force 488.3 ± 125.7 N and moment 122.2 ± 106.0 Nm, $p < .001$) than the program that had more credit hours of didactic presentation lectures (force 210.2 ± 106.5 N and moment 40.8 ± 27.4 Nm, $p < .001$).³

Dynadjust Instrument

There were 2 RCTs that used a training device called the Dynadjust instrument (LaBarge, Inc, St. Louis, MO), a device designed to help students practice applying axial forces against a set resistance.^{9,13} The resistance settings are adjustable by changing the internal spring within the tube.^{9,13} In addition, it helps students in rehearsing application of proper preload force, since minimum preload of the instrument is required for the system to report results of the manipulation effort.^{9,13} With digital electronics, the biomechanical parameters of a manipulation procedure is measured, recorded, and displayed in a computer.^{9,13}

Both RCTs were conducted by the same authors and had similar methods, such that participants were randomly assigned to a control and an intervention group.^{9,13} The control group followed the standard training program of the institution's curriculum, permitting "ad-lib" feedback.^{9,13} The intervention groups rehearsed with the Dynadjust instrument program in addition to the standard training program of the institution.^{9,13} Subjects were tested using an instrumented treatment table^{3,10-12} that displayed load-time histories. In both studies, the authors found that the students using the Dynadjust instrument rehearsal program demonstrated significant changes in performance of spinal manipulation.^{9,13} When examining the percentage of change in total force amplitude during preload for lumbar SMT,⁹ the Dynadjust group had a 5-fold increase compared to the control ($p = .0009$), and the mean rate of force increased (742 ± 345.2 N/s, $p < .001$). For thoracic SMT,¹³ significant changes were observed for several biomechanical parameters, including elements of component amplitude, speed, and duration ($p = .05$). For cervical SMT,¹³ significant values were observed in all biomechanical categories (axial force [$p = .036$], sagittal force [$p = .046$], and sagittal moment [$p = .040$]).

DISCUSSION

Summary of Evidence

Our literature review found evidence that different teaching methods exist to teach SMT to chiropractic students and that these methods are effective in nurturing skill development, knowledge transfer, and task retention among students.^{1,3,4,5,8-20} These teaching methods may be implemented into the core curriculum of the doctor of chiropractic program as teaching aids to maximize student retention, performance, and acquisition of skills necessary to effectively utilize SMT as a therapeutic technique.^{1,3,4,5,8-20} These teaching aids have a place in the future of chiropractic education and can help students develop their skills most effectively while minimizing the risk of injury from the current methods utilized for teaching.⁶ This literature review attempts to showcase the importance of incorporating various forms of teaching aids into the core curriculum of a chiropractic education. Future research is necessary to determine if these methods have the potential to translate into better clinical outcomes for patients.^{1,3,4,5,8-20}

Advantages in the educational process of learning and performing SMT may be attained with the integration of teaching methods such as instrumented CPR manikins, TMC manikins, padded contact with load cells, instrumented treatment tables, or Dynadjust instruments as outlined in this review of the chiropractic core curriculum. It is possible earlier acquisition of spinal manipulation skills may result in improvement in clinical outcomes related to patient care and safety and foster a strong foundation to optimize clinical training during the internship years of chiropractic education.^{1,3,4,7-20} Practicing SMT techniques by incorporating the various teaching methods identified in this study could also minimize the risk of injuries that may occur while students practice spinal manipulations on classmates during chiropractic education.⁵

In summary, the evidence presented does not offer a comparison or suggest a clearly superior form of teaching method to be applied as a gold standard for incorporation into the core curriculum of doctor of chiropractic programs. Further research comparing teaching methods may be able to answer this question. In the meantime, education developers and instructors at chiropractic institutions may find the incorporation of 1 or various teaching methods to be advantageous.

Strengths and Limitations

Our study has strengths. First, the authors developed a sensitive search strategy. Also, an explicit set of inclusion and exclusion criteria were defined to identify all possible relevant citations from the searched literature. Two independent reviewers conducted screening and critical appraisal in order to minimize error and bias and used a valid, well-accepted set of criteria (SIGN) for critical appraisal.²¹ Finally, the authors performed a best evidence synthesis using only internally valid studies in order to minimize bias in the reported results.

Our review also has limitations. First, the authors restricted our search to studies published in the English language, which may have resulted in the exclusion of some relevant studies. However, previous reviews have found that the restriction of systematic reviews to studies in English has not led to a bias in reported results.²³ Second, critical appraisal requires scientific judgment, which may vary between reviewers. Using a consensus process between reviewers to reach decisions regarding scientific admissibility minimized this potential bias. Additionally, the review was limited to the education of chiropractic students and thus excluded all studies regarding teaching spinal manipulation in other health disciplines. Future research with an expanded search strategy may expand the results of this review. It should also be noted that injuries were not reported in the studies included in this review. Future research should report on injuries (or lack thereof) in order to compare the safety profile of different teaching methods. Finally, it should be noted this review included predominantly those studies that evaluated teaching thoracic manipulation, and further research to examine all regions of the spine more thoroughly should be conducted and reviewed in the future.

Conclusions

The authors found evidence that several different teaching methods exist in the literature for instructing chiropractic students in SMT techniques; however, future research in this developing area of chiropractic education is suggested. Future studies should investigate the role of these teaching methods in the effectiveness of chiropractic students as practicing chiropractors, the transfer of the knowledge and skills acquired for chiropractic practice, and the application of those skills contributing to better clinical outcomes for patient populations. The objective of this review was to evaluate the literature to determine which teaching methods are currently being implemented in chiropractic education. The results suggest that a variety of teaching methods could be included in the regular curriculum of chiropractic students to aid in efficiency, development of skills, and knowledge of performance to maximize technique mastery. It is possible the transfer of these learned skills to future clinical practice may contribute to improved clinical outcomes for patient populations, and future research could expand on this potential.

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